Australian Government
Land & Water Australia

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Assessing the health of Ephemeral Rivers

Published by: Land & Water Australia

Product Code: PN30272

Postal address: GPO Box 2182, Canberra ACT 2601

Office Location: Level 1, The Phoenix
86-88 Northbourne Ave, Braddon ACT

Telephone: 02 6263 6000

Facsimile: 02 6263 6099

Email Land&WaterAustralia@lwa.gov.au

Internet: lwa.gov.au

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Assessing the Health of Ephemeral Rivers

Review of Geomorphic and Hydrologic Indicators

Tony Ladson

Cooperative Research Centre for Catchment Hydrology & Monash University

December 2003

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1. Summary

Assessing the geomorphic and hydrologic aspects of ephemeral rivers is an important part of measuring their health. Ideally, a few accurate, repeatable, rapid measurements would describe their condition and allow changes to be assessed over time.

Researchers and managers have developed a large number (hundreds) of hydrologic and geomorphologic indicators which are summarised in this review. Often a suite of indicators, developed by a management agency, will be applied to streams in a particular State or region. The geomorphic and hydrologic indicators from these approaches are discussed, focussing particularly on those suitable for ephemeral streams.

This project is aiming to measure health of ephemeral rivers so indicators need to assess departure from a healthy state, that is, they must allow a comparison with a reference condition. Generally, for geomorphic indicators, the reference condition will be the natural or pristine state of a stream. For hydrologic indicators, a comparison is usually made between some facet of the current and natural flow regime.

There have been several recent conceptual advances in the design of indicators that should be considered when selecting indicators for this project and are highlighted in this review.

- A rigorous procedure for determining reference conditions for geomorphic indicators has been developed as part of the Australian River Assessment System (AusRivAS) Physical Assessment Protocol (Parsons, et al. 2002). The determination of reference conditions has been a weakness of many assessment procedures which this new approach can overcome, provided there are sufficient natural or 'least impacted' sites available for comparison.
- In hydrology, recent work has led to the development of variance-corrected indicators, which take account of the natural variation in flow regimes (SKM 2002; 2003). These assume that the greatest impact on health will occur where flow is changed to the extent that current conditions are outside the range of natural variation. The biological relevance of these indictors is being considered as part of the Murray-Darling Basin Commission's Sustainable Rivers Audit.
- Hydraulic (in addition to hydrologic) indictors have been included in recent environmental flow assessments undertaken by the Cooperative Research Centres for Catchment Hydrology and Freshwater Ecology (Stewardson, 2001; Stewardson and Cottingham 2002). These indicators include consideration of the physical aspects of a stream channel and floodplain, and measure features that are more likely to be biologically meaningful than hydrologic approaches. The downside is that they require more data and are computationally intensive.

There is also an existing comprehensive assessment of the geomorphic condition of streams within catchments that overlap with, or are near to, those in the current study. This work, by Earth Tech Engineering Pty Ltd (2003), should inform the development of procedures and selection of indicators for the geomorphic assessment of this ephemeral rivers project.

The next stage in this project is to refine the candidate set of indicators to be used to assess ephemeral stream health. This review is meant to provide the back ground material that will inform:

- Discussions between scientists;
- Trial calculation and measurement of indicators;
- Searches for existing data sets; and
- Consultation with managers.

2. Introduction

2.1. Background

This review is part of project developed by the National Rivers Consortium that aims to quantify health in ephemeral rivers. This project is focused on ephemeral rivers in South Australia near to Adelaide. The project aims to identify the most appropriate methods to assess health in these streams but is also intended to support further development so that ephemeral streams, in other areas of Australia, can also be assessed.

The project is being undertaken by the Cooperative Research Centres for Catchment Hydrology and Catchment Ecology. These CRCs are consortiums of Universities and industry partners with researchers based at University of Adelaide, Griffith University, University of Canberra, University of Melbourne and Monash University. Tony Ladson, Civil Engineering, Monash University is the author of this review.

2.2. What is river health and how can it be measured?

This project aims to develop and test methods to quantify health in ephemeral rivers. A key first step in this project is to decide those aspects of health that need to be measured.

Using the term 'river health' is controversial and there has been much learned discussion about whether a term that has clear application to an individual organism (such as a human) can be applied to a complex system made up of many components such as a river. Never-the-less, river health is a popular and useful concept. Usually the assessment of health involves comparing the current condition of a river, with some reference state. The further from reference, the less healthy the river. One approach is to use a reference state based on a desired future condition. A healthy river would then correspond to one that matched our desired state. A challenge with this approach is to get community agreement about the desired future state. One idea used by the United States EPA is to aim for rivers that are swimmable and fishable.

An alternative approach is to choose a reference state is a 'natural' or pristine river. This is usually considered as a river before European settlement. Assessing health then becomes a comparison between the current and natural conditions. A challenge here is that 'natural' conditions can be difficult to define. There may be few examples of natural streams remaining, limited data about pre-European conditions and there would be extensive variation within streams, and between streams, even under natural conditions.

2.3. Role of indicators in River Health assessment

Streams are complex and multi-faceted: a complete assessment of differences between a natural and reference stream would be an impossible task. Instead, certain aspects of a stream are chosen and these are used to undertake a comparison. The selection of river health indicators is determined by those aspects of a stream considered to be important.

The choice of indicators is, to some extent, subjective, so it is appropriate to have input from scientists, managers and the community to the selection procedure. The large range of indicators described here, is meant to provide the background to this process.

A important consideration is the purpose of the river health assessment. Examples include:

- One-off, "snap-shot", measurements of river health, that are not intended to be repeated in the future.
- Assessments that are part of a management system.

River health assessments can be an important part of stream management by providing information that is useful for:

- Setting objectives;
- Setting priorities;
- Tracking progress against goals;
- Determining the effectiveness of management actions; and
- Warning of changes that require intervention.

It is assumed that the indicators developed for this project will become part of the process and activities used to manage Ephemeral Rivers.

2.4. Indicator frameworks for river health assessment

The choice of indicators is also influence by the framework to be used. One common indicator framework is the Pressure State Response model that was developed by the OECD and used for the State of the Environment Reporting in Australia (ASOE, 2001).

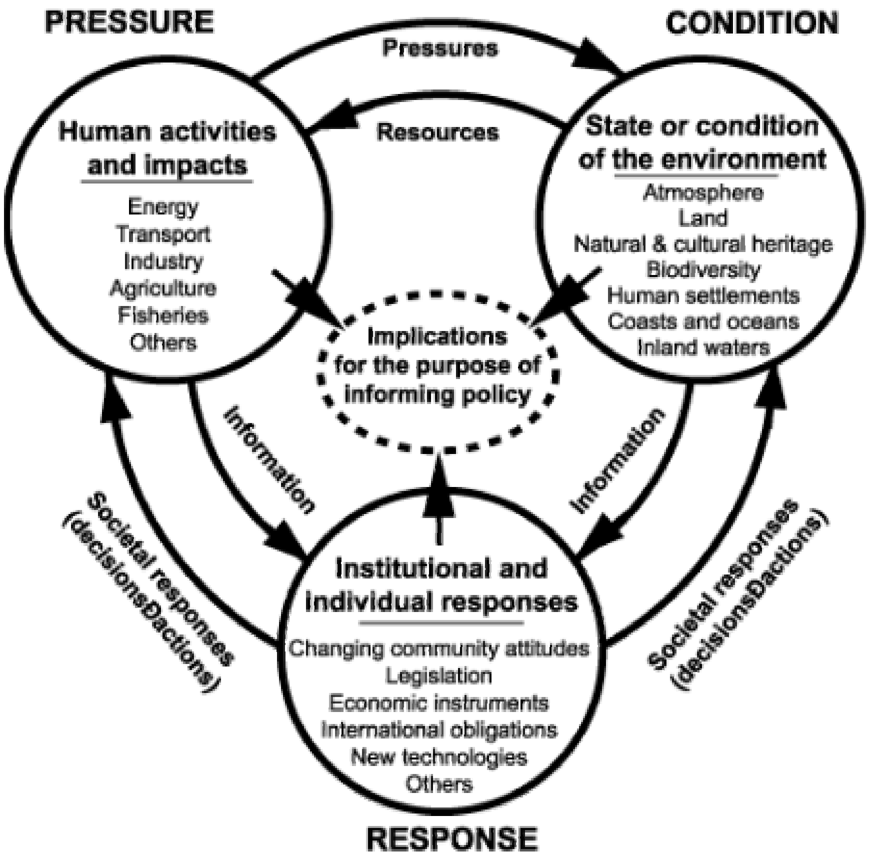

Figure 1 – Pressure, State, Response Indicators (ASOE, 2001)

State Indicators – measure the state or condition of the resource. An assessment of the features of interest and a comparison with some standard. For ephemeral rivers, an example of a state indicator could be the number of fish species present in a river compared with the number that were there naturally.

Pressure Indicators – measure processes, features and activities that are likely to make a system less like reference i.e. less healthy. For ephemeral streams, this could include number of capacity of sewage treatment plants that are discharging into a river. Some pressure indicators for inland waters have been developed by Environment Australia (ASOE 2001).

Response Indicators – Human responses to issues identified by the pressure and state indicators. For ephemeral streams, this could include the number of towns where there are measures to reduce storm water flow from urban areas.

The brief for this project suggests that the objective is to assess the ‘state’ or condition of ephemeral streams. Pressure and response indicators would need to be considered in a separate project.

2.5. Existing Indicator Systems

This review is mainly based on existing approaches to river health assessment that have been developed in Australia and elsewhere and includes discussion of:

- Australian River Assessment System (AusRivAS) - Physical Assessment Protocol;
- Index of Stream Condition;
- Assessment of River Condition;
- River Styles;
- Pressure Biota Habitat;
- Environmental Condition of Victoria's streams;
- State of the Rivers;
- Riparian, Channel and Environmental Inventory; and
- Watercourse condition assessment in the Mt Lofty Ranges.

Other indicator systems have been reviewed but are not considered in detail here. These include:

- Index of Aquatic Environmental Quality (Office of the Commissioner for the Environment, 1988).

  Does not include geomorphic or hydrologic indicators.

- Estuarine Health Index (Cooper et al. 1994).

  Does not include geomorphic or hydrologic indicators.

- River Habitat Survey (RHS) (Fox, 1998).

  RHS is reviewed by Parsons et al. (2000). From this review it seems unlikely that RHS would contribute to the approaches discussed in this review.

- HABSCORE (USEPA Rapid Bioassessment Protocols, Barbour et al., 1999).

HABSCORE is reviewed by Parsons et al. (2000). Most of the relevant procedures from HABSCORE have been incorporated into the AusRivAS Physical Assessment Protocol.

2.6. Key Geomorphic Features of Ephemeral Rivers

The review of geomorphic indicators, in section 3, shows that procedures have been developed to assess a large number of stream features including bed, banks, plan form, substrate and channel size and shape.

Many of these features will be important for ephemeral rivers, but is it likely that some features will be critically important. Our preliminary review suggests that the occurrence and behaviour of pools is one key feature. Pools have been shown to be biologically important as refuges (Boulton, 1989; Boulton and Lake, 1992) and primary production in pools is a key feature of some semi-arid streams (Bunn and Davies, 1999).

Pools are also vulnerable to disturbance. Stream incision can drain pools through bed level lowering. Sedimentation can fill them in. Pumping from pools could cause loss of key refuges. Farm dams may reduce the flow of water to pools downstream but can result in increased numbers of pools upstream (assuming a farm dam behaves as a pool).

This suggests that geomorphic indicators that measure the occurrence of pools and threats to pools, such as incision or sedimentation, are likely to be particularly important in ephemeral streams. Most geomorphic indicators have been developed in temperate streams so may not have sufficient emphasis on pools.

Another key issue is the highly variable nature of ephemeral streams even under natural conditions. The variable hydrologic regime can also lead to marked changes in geomorphic characteristics over time. River health indicators need to be selected that can give reasonable results despite this variation.

2.7. Key Hydrologic and Hydraulic Features of Ephemeral Rivers

An important task of this project is to determine the key hydrologic facets and hydraulic events that need to be assessed as part of determining the health of ephemeral rivers. A preliminary list is presented here, which will require further discussion between stream ecologists, geomorphologists and hydrologists. A wide-range of possible hydrologic indicators are described in section 4.

Key hydrologic features of ephemeral rivers are likely to include:

- Frequency of cease to flow periods - this will determine how often pools are required to provide refuges
- Duration of cease to flow periods – this will determine how long pools need to last before they are replenished by the next flow event;
- Water extraction during low flow or cease to flow periods – a measure of the impact of human use on the persistence of pools;

Key hydraulic events that are likely to influence health of ephemeral rivers include:

- Bed scouring or some other indicator of pool formation;
- Sediment transport or some other indicator of pool infilling;
- Spawning and migration cues for biota;

- Channel forming flow – whether changes to flow are likely to make the channel larger or smaller; and
- Frequency of overbank flow – how often there is transfer of water, nutrients and carbon between channels and floodplains.

3. Possible Indicators for assessing geomorphic change in ephemeral rivers

3.1. Introduction

This section describes the geomorphic indicators associated with existing approaches to measuring river health. The suitability and limitations of these indicators for use in ephemeral rivers is discussed where possible.

3.2. Australian River Assessment System (AusRivAS) Physical Assessment Protocol

The AusRivAS physical assessment protocol is a comprehensive and innovative approach to assessing the physical conditions of inland streams (Parsons et al. 2002). In summary, the approach involves

1. Choosing a number of reference sites that represent 'least disturbed' conditions
2. Measuring a large amount of information at these sites;
3. Developing models that allow prediction of physical features at test sites – the *expected* physical features;
4. Measuring the actual physical features that occur at the sites – the *observed* features;
5. Using the ratio Observed/Expected to assess the condition of the test sites.

Two types of variables are measured: control variables, that are not influenced by disturbance, and response variables, that may be. The control variables are used to predict the physical features that are expected to be present based on models developed from measurements at reference sites. Over 90 variables are measured in total (See Appendix 1). The modelling procedure is explained in Simon and Norris (2000) and the approach to predicting geomorphic features is detailed in Davies et al. 2000. A field manual is available on the internet http://ausrivas.canberra.edu.au/Geoassessment/Physchem/Man/Protocol/chapter1.html.

3.2.1. Suitability and Limitations

The AusRivAS physical assessment protocol is probably the most rigorous of any physical assessment method as it involves assessment of a large number of variables and a statistic approach to comparing test and reference sites. It is likely that this approach will form an important basis for the development of indicators for ephemeral streams.

Field assessment of the South Australian sites along with discussions amongst the project group will be required to resolve the following issues:

- Whether there is sufficient reference sites available to allow the development of predictive models of physical condition;
- The need to add to, or exclude, certain response variables in the AusRivAS procedure (see Appendix 1).

  Additional indicators that should be considered, relate to the occurrence and behaviour of pools (see the discussion above).

The AusRivAS physical assessment protocol has also had limited application and, so far, has not been chosen by the Murray-Darling Basin Commission as part of the Sustainable Rivers Audit. It would be appropriate to understand their reservations before adopting it for the current project.

3.3. Index of Stream Condition

The Index of Stream Condition was developed to assess the condition of streams in Victoria (Ladson and White, 1999). The ISC provides scores for five components (sub-indices) of stream condition:

- Hydrology (a comparison current and natural flow regime);
- Physical form (discussed below);
- Streamside zone (based on type of plants; spatial extent, width, and intactness, of riparian vegetation; regeneration of overstorey species, and condition of wetlands and billabongs);
- Water quality (based on an assessment of phosphorus, turbidity, electrical conductivity, and pH); and
- Aquatic life (based on occurrence of families of macroinvertebrates).

Approximately 900 sites in Victoria have been assess and results are available on the internet see www.vicwaterdata.net.

The main geomorphic indicators in the ISC are:

1. Bed erosion and/or sedimentation;
2. Bank stability;
3. Physical habitat, including abundance and origin of course woody debris; and
4. Influence of artificial barriers.

The first three indicators are assessed in the field, while the influence of artificial barriers can be assessed in the office and is based on the number and height of barriers downstream of a particular reach.

For the field indicators, a rating system is used based on a visual assessment of a field site. Indicators are scored on a 5-point scale in comparison to natural or desirable conditions. A field guide (White and Ladson, 1999) has been prepared to assist with scoring and assessors are trained. Results of the Victorian ISC have been independently audited.

3.3.1. Suitability and Limitations

The strength of this the ISC approach is that it was been widely used and results have been collected by Catchment Management Authorities and now form part of a management system. ISC scores are used as part of planning and target setting by waterway managers and assessments will be repeated every 5 years to track changes and reassess priorities.

A weakness of the ISC is the lack of a well defined reference condition. Whereas, AusRivAS uses a rigorous approach to reference site selection and measurement, the reference for the ISC involves the pragmatic application of a the concept of a 'natural' or 'pristine' stream. Current conditions are compared with what a reference panel expected a natural stream might be like. It may be difficult to apply a similar concept in ephemeral rivers where physical stream condition is likely to be highly variable even under natural conditions.

Despite this limitation, the ISC framework may be useful for the current project. The ISC divides condition up into 5 components and each of these forms a sub-index to an overall assessment. A panel of experts was consulted to chose and then develop indicators for each of these sub-indexes (Ladson et al. 1999). A similar approach may be useful for the current project.

3.4. Assessment of River Condition

An Assessment of River Condition (ARC) was undertaken as part of the National Land and Water Resources Audit (Norris et al. 2001).

Geomorphic indicators include:

- Bed-load condition;
- Longitudinal barriers – dams; and
- Lateral barriers – levees.

3.4.1. Bed-load condition

Catchment disturbance, bed and bank erosion can lead to increases in sediment that smother the original bed material in layers of sand and silt. This reduces habitat availability, infills pools and creates barriers to fish passage.

The bed-load condition index measures the amount of sediment accumulation on the stream bed.

$$BCI = 0.33 - 0.33\log_{10}(CDEP)$$

Where: *BCI* = the bedload condition index.

CDEP = is the depth of sediment accumulation in metres.

The depth of sediment accumulation is based on sediment modelling carried out at part of the National Land and Water Resources Audit.

3.4.2. Longitudinal Barriers – Dams

Barriers such as dams or weirs can restrict the longitudinal movement of biota such as fish. Barriers within, and upstream and downstream of a reach are likely to be important as biota may migrate upstream or downstream.

$$LongI = 1 - \left[\left(w_0 b_0 + \frac{w_1 b_1 + w_{-1} b_{-1}}{2} + \frac{w_2 b_2 + w_{-2} b_{-2}}{3} + \ldots + \frac{w_4 b_4 + w_{-4} b_{-4}}{5}\right)\right]$$

Where: *LongI* = Longitudinal Connectivity Indicator.

b_0 = barrier in a reach.

w_0 = weight applied to the barrier (depends on size).

b_1= barrier in the next reach upstream.

b_{-1}= barrier in the next reach downstream.

3.4.3. Lateral Barriers – Levees

The transfer of water and material between rivers and floodplains is known to be an important aspect of stream health. Levees, constructed along streams restrict this transfer. The impact of levees can be summarised in an index as follows.

$$LatI = 1 - \left(\frac{L_l}{2L_r} \right)$$

Where: $LatI$ = the lateral connectivity measure

L_l = length of levees in a reach

L_r = length of a reach

3.4.4. Suitability and Limitations

These indicators were developed for a national assessment of river condition so have been designed to be measured from existing data sets, rather than requiring field visits, and, by necessity represent a broad brush approach. However, the issues of sediment accumulation, longitudinal and lateral connectivity are clearly important in ephemeral rivers, and modified versions of these approaches, that are suitable for local conditions, are likely to be appropriate.

3.5. River Styles

Rivers styles is a geomorphic classification system for river reaches. There is a hierarchy of river styles with the highest level of classification based on channel confinement. A reach can confined (no, or only occasional floodplain pockets), partly confined (discontinuous floodplain pockets) and alluvial (continuous floodplains). There are a number of levels beneath this initial classification based on distinctions between geomorphic attributes of the reach such as channel features, bed and bank erosion and sediment type and size.

The initial development of river styles was as a river classification system but it has recently been extended for use in assessing geomorphic condition using a 3 step process (Fryirs, 2003).

First, the river style is identified which determines the indicators that are used to measure condition. For example, an alluvial reach has extensive capacity for adjustment so indicators could include channel shape, width, depth or sediment size. For a confined reach, there is much less capacity for adjustment so it is appropriate to measure fewer indicators.

Secondly reference condition is determined. Reference condition is based on a reach (with the same river style) which has adjusted to the prevailing boundary conditions. This takes account of human induced change and is not based on the use of a pre-disturbance reference.

Thirdly, the reach is compared to the reference to determine a score for its condition. Fryirs (2003) provides a series of questions to guide this assessment.

River styles can be used to classify reaches as good (close to natural), moderate (degraded but with potential to be rehabilitated) and poor (heavily degraded with little prospect for rehabilitation).

3.5.1. Suitability and Limitations

The main limitation with using the river styles approach to assess the geomorphic condition of ephemeral streams in South Australia is that the appropriate styles needs to be available and applied to the streams in the study area. There has been development of river styles for some parts of the study catchments for a project undertaken by Earth Tech Engineering Pty Ltd (2003) (see section 3.10). These include streams in the Onkaparinga, Torrens and Gawler Catchments. However the difficulty in extending the system of condition assessment using river styles classification system to the study catchments, and ephemeral streams in general, is beyond the scope of this project.

3.6. Pressure-Biota-Habitat

The NSW Department of Infrastructure, Planning and Natural Resources is development a stream assessment system know as Pressure – Biota – Habitat (PBH). This measures human pressure on a stream, the biota present and the available habitat. Geomorphic indicators include (Gawne, 2001):

- Substratum size;
- Channel depth;
- Bank alteration;
- Bank stability;
- Bed stability; and
- Large woody debris.

The PBH method is currently being trialled in 12 NSW subcatchments (Gawne, 2001).

3.6.1. Suitability and Limitations

Results for the trials of PBH are not yet available and there is likely to be less risk in using other assessments methods for this ephemeral rivers project.

3.7. Environmental Condition of Victoria's Streams

In 1986, the Victorian State Government commissioned a State of the Streams Survey (SSS) to assess physical stream conditions. The survey examined 868 sites that were chosen to be representative of all stream types within 28 drainage basins throughout the state. At each survey site, approximately 200 variables were recorded including catchment land use, stream bed and bank material, riparian vegetation, channel characteristics and aquatic habitat. Several photographs were also taken (Tilleard and DWR, 1986). A subset of these variables (10 of the 200) was used by Mitchell (1990) to develop an assessment of the environmental condition of Victoria’s rivers and streams (Table 1 -).

The geomorphic indicators used in this assessment were:

- Bed composition
- Proportion of pools and riffles
- Water depth
- Erosion and sedimentation

3.7.1. Suitability and Limitations

Mitchell (1990) defines environmental condition as the suitability of a stream as habitat for fish and aquatic invertebrates and, to a lesser extent, the condition of the riparian zone as habitat for native organisms. Therefore, ratings attempt to provide an absolute measure of environmental condition defined as habitat suitability. Independent checking of Mitchell’s procedure shows that it successfully performed this task. Habitat suitability ratings were checked by experienced professional field biologists and there was reasonable agreement (Barmuta et al., 1992).

The criteria reported by Mitchell to develop environmental ratings is not based on comparison with reference conditions so will only be appropriate in limited areas. They not likely to be useful for ephemeral streams in South Australia as many streams in natural condition would be rated poorly. Some individual indicators may be useful.

Table 1 - Criteria used by Mitchell (1990) to determine environmental ratings for rivers in Victoria, adapted from (Barmuta et al. 1992).

	Very Poor	Poor	Moderate	Good	Excellent
1. Bed composition					
Minor stream[1]	All sand	Gravel, sand	Gravel, some cobbles, some sand	With at least 10% cobbles mainly shingle	Boulders, cobbles, shingles, small amount gravel or finer
Tributary stream[2]	N/A	All sand	Gravel, sand	Mainly shingle, gravel	Shingle, cobble, gravel
Major stream[3]	N/A	N/A	All sand	Shingle, gravel, sand	Shingle, cobbles present
2. Proportion of pools and riffles					
Minor stream	100% riffle or pool	90% riffle or pool	70-80% riffle or pool	60% riffle or pool	50% riffle or pool
Tributary stream	Intermittent pools	All pools	<10% riffles	10-30% riffles	>30% riffles
Major stream	Intermittent pool or very shallow	N/A	100% pools	N/A	some riffles
3. Bank vegetation					
All	Exotic ground cover with bare ground, occasional tree	Exotic ground cover, little native overstorey or understorey or predominantly exotic cover.	Moderate cover, mixed native/exotics, or one side cleared, other undisturbed	Minor clearing	Mainly undisturbed native vegetation
4. Verge vegetation					
All	Bare or pasture	Very narrow corridor of native vegetation or exotics	Wide corridor mixed native and exotics, or one side cleared, and other native and wide	Mainly undisturbed native, <30m wide or some exotics or reduced cover of natives	Mainly undisturbed native vegetation, >30m wide
5. Cover for fish					
All	none	Poor	Moderate	Good	Abundant
6. Average flow velocity					
Minor stream	0	0.1-0.2 m s^{-1}	0.3-0.6 m s^{-1}	0.6-0.7 m s^{-1}	>0.8 m s^{-1}
Tributary stream	0	0.1-0.2 m s^{-1}	0.3-0.6 m s^{-1}	0.6-0.7 m s^{-1}	>0.8 m s^{-1}
Major stream	N/A	0	0.1 m s^{-1} (pools)	0.2 m s^{-1} (pools)	0.3 m s^{-1} (pools)
7. Water depth					
Minor stream	Dry or trickle	< 0.2 m	0.3-0.5 m	0.6-1 m	> 1.0 m
Tributary stream	Dry or trickle	< 0.2 m	0.3-0.5 m	0.6-1 m	> 1.0 m
Major stream	< 0.3 m	0.4 m	0.5-0.9 m	1.0-2.0 m	> 2.0 m
8. Underwater vegetation					
All	0 or > 80% cover	1-5% or 60-80% cover	5-20% cover	20-30% cover	30-60% cover
9. Organic Debris					
All	0	0-10% cover	10-20% cover	20-40% cover	40% cover
10. Erosion/sedimentation					
All	Extensive	Significant	Moderate, affecting parts of reach	Only spot erosion	Stable no erosion or sedimentation

[1] minor streams - catchment area less than 5 000 ha
[2] tributary streams - catchment area between 5 000 and 30 000 ha
[3] major streams - catchment area greater than 30 000 ha

3.8. State of the Rivers

The State of the Rivers Project was conducted under the direction of the Queensland Department of Primary Industries. The aim of the project was to provide baseline information that could assist with setting priorities for stream rehabilitation and to determine trends in stream condition (Anderson, 1993; Jackson and Anderson 1994).

The assessment technique, the 'Anderson' method, involves a field-based appraisal of condition at selected sites throughout a river system. Assessments are made on data sheets that enable descriptions of:

- the climate and regional land system of the catchment;
- subcatchment features - land use, soils, geology, slope, gradient;
- site features - land use, vegetation, land tenure, floodplain features;
- channel form, shape and dimensions;
- banks, physical condition and process;
- bed and bars, physical condition and process;
- vegetation, aquatic, bank, riparian;
- aquatic habitat classification and condition; and
- scenic, conservation and recreational value.

Ratings are produced using formulae, which combine the data weighted in terms of their relative importance (Jackson and Anderson, 1994). Ratings range from very good to degraded with streams classified on a five point scale as shown in Table 2 - . The very good condition criteria is set using a local undisturbed site as a reference so that the ratings indicate how far other sites have degraded from this standard.

Table 2 - Condition rating for the State of the Rivers project (Jackson and Anderson, 1994)

Condition Category	Rating
Very Good	81-100%
Good	61-80%
Moderate	41-60%
Poor	21-40%
Very Poor	0-20%

The procedure uses a similar sampling technique to that in the State of the Streams Survey conducted in Victoria (Ian Drummond and Associates Pty Ltd, 1985; Tilleard and DWR, 1986; Mitchell, 1990). Measuring sites (about 50m long) are chosen that represent the condition of larger homogeneous reaches. The measuring sites are assessed in detail and this information is used to infer the condition of the reaches.

The Anderson procedure has been applied to streams in Queensland including the Maroochy River (Anderson, 1993c), Bremer River (Telfer et al., 1998), Herbert River (Moller, 1996), Mary River (Johnson, 1997), Lockyer Creek (Carter, 1997) and Condamine River (Phillips and Moller, 1995). It has also been applied in New South Wales (Jim Armstrong, Department of Land and Water Conservation, NSW pers. comm.).

3.8.1. Suitability and limitations

The State of the Rivers project has enjoyed support since its development, which suggests that results are seen as being useful. Assessment is limited to the physical characteristics of the stream channel and surrounds and the instream and riparian vegetation. There is no assessment of hydrology, water quality or aquatic biota.

Ratings are based on formulae with a number of dependent variables and a series of calculation steps. For example, calculation of the Aquatic Habitat Index, requires consideration of 17 different cover types, each with its own weighting. The values for each cover type are scaled using a 3rd order quadratic function and then weighted and summed with the final output being rescaled using a logarithmic function to amplify the ratings where there is limited cover (Anderson, 1993b, 45). Most of the rating procedures are straightforward to apply since software has been developed to undertake the calculations but the system is more difficult to change than one based on tabulated ratings and harder to explain to users. It will also be harder to modify it for use in other areas where different ratings and weights may be appropriate. Given the lack of sophistication in other areas of the stream assessment, a more straightforward approach to calculating ratings seems appropriate.

The individual indicators and field sheets may be appropriate to guide development of indicators for ephemeral streams.

3.9. Riparian Channel and Environmental Inventory

A Riparian Channel and Environmental (RCE) inventory was developed to assess the physical and biological condition of small streams in lowland areas where non-point source pollution and agriculture dominate (Petersen, 1992). The RCE has been used in Sweden, Italy and Idaho (US). A value for the RCE is obtained by rating the stream on the basis of 16 characteristics as shown in Table 3. The score for each characteristic is added to provide an overall classification for the stream along with a colour coded rating as shown in Table 4.

The geomorphic indicators used in the RCE are:

- The number and stability of rocks and logs in a channel;
- Channel structure including width to depth ratio and capacity in comparison with annual peak flow;
- Channel sediments including type and amount of sediment accumulation;
- Stream bank stability;
- Bank undercutting;
- Feel and appearance of stony substrate;
- Occurrence and spacing of riffles, pools and meanders.

3.9.1. Suitability and limitations

The RCE inventory is a rapid assessment method that can provide an overview of stream condition. It is based on the assumption that the environmental condition of small streams can be assessed by an appraisal of the physical condition of the riparian zone and stream channel. Petersen (1992) argues that this assumption will be true in landscapes where non-point source pollution and agriculture dominate. This assumption justifies the exclusion of indicators of water quality, hydrology and aesthetics.

These assumption is not likely to be appropriate in ephemeral streams in South Australia where our conceptual model is that hydrologic change is likely to be a critical parameter. However, some of the individual indicators may be worth considering.

Table 3 - Assessment of the RCE (Riparian, Channel and Environmental) inventory (Petersen, 1992)

Indicator	Score
1. Land use pattern beyond the immediate riparian zone	
Undisturbed, consisting of forest, natural woodlands, bogs and/or mires	30
Permanent pasture mixed with woodlots and swamps, few row crops	20
Mixed row crops and pasture	10
Mainly row crops	1
2. Width of riparian zone from stream edge to field	
Marshy or woody riparian zone >30 m wide	30
Marshy or woody riparian zone varying from 5 to 30 m	20
Marshy or woody riparian zone 1-5 m	5
Marshy or woody riparian zone absent	1
3. Completeness of riparian zone	
Riparian zone intact without breaks in vegetation	30
Breaks occurring at intervals of > 50 m	20
Breaks frequent with some gullies and scars every 50 m	5
Deeply scarred with gullies all along its length	1
4. Vegetation of riparian zone within 10 m of the channel	
>90% plant density of non-pioneer trees or shrubs, or native marsh plants	25
Mixed pioneer species along channel and mature trees behind	15
Vegetation of mixed grasses and sparse pioneer tree or shrub species	5
Vegetation consisting of grasses, few trees shrubs	1
5. Retention devices	
Channel with rocks and old logs firmly set in place	15
Rocks and logs present but back filled with sediment	10
Retention devices loose; moving with floods	5
Channel of loose sandy silt; few channel obstructions	1
6. Channel structure	
Ample for present and annual peak flows, width/depth<7	15
Adequate, overbank flows rare, W/D 8 to 15	10
Barely contains present peak, W/D 15 to 25	5
Overbank flows common, W/D>25 or stream is channelised	1
7. Channel sediments	
Little or no channel enlargement resulting from sediment accumulation	15
Some gravel bars of coarse stones and well-washed debris present, little silt	10
Sediment bars of rocks, sand and silt common	5
Channel divided into braids or stream is channelised	1
8. Stream-bank structure	
Banks stable, of rock and soil held firmly by grasses shrubs and tree roots	25
Banks firm but loosely held by grass and shrubs	15
Banks of loose soil held by a sparse layer of grass and shrubs	5
Banks unstable, of loose soil or sand easily disturbed	1
9. Bank undercutting	
Little or none evident or restricted to areas with tree root support	20
Cutting only on curves and at constrictions	15
Cutting frequent, undercutting of banks and roots	5
Severe cutting along channel, banks falling in	1

Indicator	Score
10. Stony substrate; feel and appearance	
Stones clean, rounded without sharp edges; may have a blacked colour	25
Stones without sharp edges and with slight sand, silt, gritty feel	15
Some stones with sharp edges obvious gritty cover	5
Stones bright; silt, grit cover and sharp edges common	1
11. Stream bottom	
Stony bottom of several sizes packed together, interstices obvious	25
Stony bottom easily moved, with little silt	15
Bottom of silt, gravel and sand, stable in places	5
Uniform bottom of sand and silt loosely held together, stony substrate absent	1
12. Riffles and pools, or meanders	
Distinct, occurring at intervals of 5-7x stream width	25
Irregularly spaced	20
Long pools separating short riffles, meanders absent	10
Meanders and riffles/pools absent or stream channelised	1
13. Aquatic vegetation	
When present consists of moss and patches of algae	15
Algae dominant in pools, vascular plants along edge	10
Algal mats present, some vascular plants, few mosses	5
Algal mats cover bottom, vascular plants dominate channel	1
14. Fish	
Rheophilous fish present, native population, present in most pools	20
Rheophilous fish scarce and difficult to locate	15
No rheophilous fish, some lentic fish present in pools	10
Fish absent or scarce	1
15. Detritus	
Mainly consisting of leaves and wood without sediment	25
Leaves and wood scarce; fine flocculent organic debris without sediment	10
No leaves or weedy debris; coarse and find organic matter with sediment	5
Fine, anaerobic sediment, no coarse debris	1
16. Macrobenthos	
Many species present on all types of substrate	20
Many species but only in well-aerated habitats	15
Few species present but found in most habitats	5
Few if any species and only in well-aerated habitats	1

Table 4 - Classification of streams based on the RCE (Riparian, Channel and Environmental) inventory (Petersen, 1992)

Class	Score	Evaluation	Colour	Recommended action
I	293-360	Excellent	Blue	Biomonitoring and protection of existing status
II	224-292	Very good	Green	Selected alterations and monitoring for changes
III	154-223	Good	Yellow	Minor alterations needed
IV	86-153	Fair	Brown	Major alterations needed
V	16-85	Poor	Red	Complete structural reorganisation

3.10. Watercourse Rehabilitation Priority Setting Project

A rehabilitation and priority setting project was undertaken on watercourses near Adelaide by Earth Tech Engineering Pty Ltd for the combined Catchment Water Management Boards of the Mt Lofty Ranges (Northern Adelaide and Barossa, Onkaparinga, Patawalong, and Torrens) (see Figure 2). A report on this work was published in November 2003 (Earth Tech Engineering Pty Ltd, 2003).

The focus of this project was to develop a method to describe the values of, and threats to, streams, and use this information to set priorities for works to protect and restore these streams.

The project had several specific objectives as follows:

- To identify assets and threats to those assets;
- To provide guidance on trends in asset condition;
- To identify threats to stream health and opportunities to improve stream health;
- To develop a method to assign priorities to reaches and sub-catchments to reduce to assets.

In achieving the project aims, four deliverables were produced for the Boards.

- Production of a geomorphic stream style classification of watercourses of the Mt Lofty Ranges and the classification of 5,410 km of stream.
- A desktop risk assessment that derived a relative ranking of reach segments according to physical characteristics and exposure to threatening processes.
- Development of a field survey methodology and design of a database to store collected field data.
- Development of the final priority setting process. This computer-based system can store data, calculate risk scores, generate graphic representations of reach condition and allows comparison of field observations taken at different times.

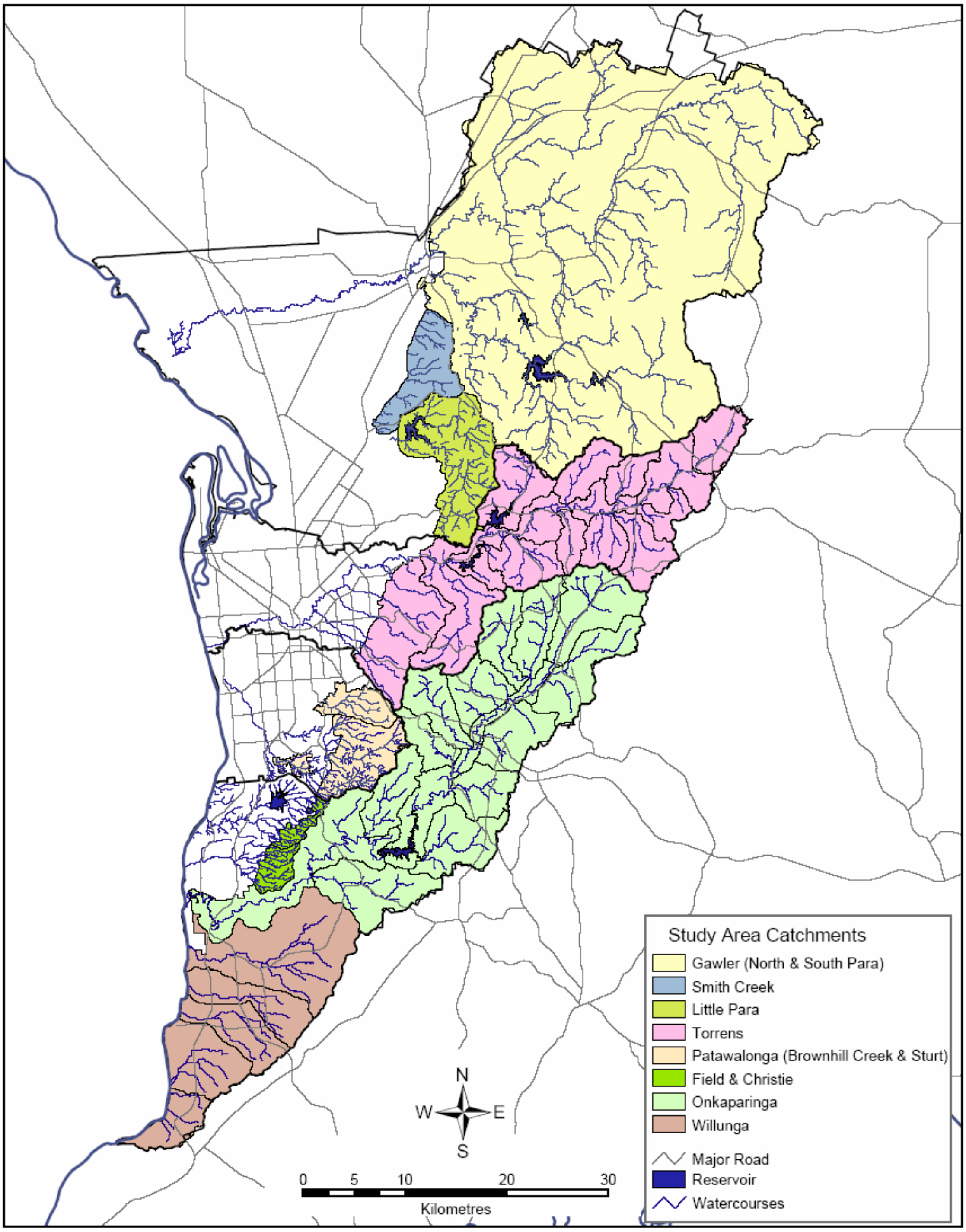

Figure 2 – Study area for the watercourse rehabilitation priority setting project (Earth Tech Engineering Pty Ltd, 2003)

Twenty geomorphic styles were used to classify streams in this study and those that are discontinuous, but intact were found to be the most susceptible to change from pre-European condition. Features assessed in the field include:

- Valley Setting Features (e.g. is the reach in a narrow confined valley or broader floodplain?);
- Valley Floor Features (e.g. list the geomorphic units such as benches or chains-of-ponds);
- Floodplain features (geomorphic floodplain features such as abandoned channels);
- Channel features (e.g. channel geometry and sediment type);
- Bed stability;
- Bank stability;
- Connectivity;
- Instream structures (e.g. woody debris); and
- Bed vegetation;

Geomorphic classification of a reach was turned into a threat rating based on rarity, naturalness and importance in terms of ecological processes.

3.10.1. Suitability and limitations

This project was concerned with the assessment of threats to stream condition and priority setting for future works rather than condition assessment, so the results and procedures may not be directly suitable for assessing the health of ephemeral rivers. However the geomorphic assessment appears to have been comprehensive and should inform the current study.

Geomorphic styles were developed for streams in the Onkaparinga, Torrens and Gawler catchments and written descriptions, field sheets and photographic examples are available (Earth Tech Engineering Pty Ltd, 2003). This work is likely to be an appropriate guide to geomorphic classification of streams for the current project for at least some areas of the study catchments.

4. Possible indicators for assessing hydrologic change in ephemeral rivers

4.1. Introduction

A large number of indicators, probably more than 500, have been developed to assess changes to flow regimes. Hydrology is a data rich science so developing indicators is straightforward, the difficulty is to decide which are biologically relevant and, for this project, which are appropriate for ephemeral rivers.

Clearly, a comprehensive review of all the available indicates is not feasible. Instead this review focuses on three main areas.

- Applications of hydrologic indicators in Australia. These applications are the main source of indicators to be considered for use in ephemeral rivers.
- A few key indicators that should be considered for this project. These indicators are mainly drawn from work undertaken for the Sustainable Rivers Audit and includes "variance-corrected" approaches, which is an important recent development.
- Links between hydrologic indicators and hydraulic indicators. The use of hydraulic indictors is an important conceptual advance but require more data and effort to calculate.
- A brief discussion of surrogate indicators that may be appropriate where there is limited hydrologic data.

4.1.1. Data requirements

Most indicators require information on current flows and 'natural' or unimpeded flows, that is, what the flow would have been like without extraction, dams, or other developments. Ideally, a current and natural record of daily flows would be available at each site where indicators are to be calculated. If only monthly, or annual, flows can be accessed, then a smaller set of indictors is available.

It is likely that a indicators that can be used will be severely limited by the data that is available. Generating natural monthly flows will usually require hydrologic modelling. The extent of data, and required modelling will depend on site selection and the project budget.

There are more stringent data requirements for the calculation of hydraulic indicators. These require flow data along with channel cross-sections and roughness values. Stage heights, along with flow data are important for model calibration.

4.2. Applications of Hydrologic Indicators

4.2.1. National Land and Water Resources Audit

A hydrological disturbance index was developed by Norris et al. (2001) for the National Land and Water Resources Audit. This includes four indicators based on:

- mean annual flows;
- monthly flow duration curves;
- timing of high and low flow months; and
- differences in amplitude between high and low flow months.

In each case, the index value is based on current and natural flows.

These indicators were further developed as part of the Sustainable Rivers Audit.

4.2.2. Sustainable Rivers Audit

A series of indicators are under review as part of the Murray-Darling Basin Commission's Sustainable Rivers Audit (SRA). These indices are based on differences between natural and current flow as characterised by:

- The main annual flow;
- Ordinates of the flow duration curve;
- Differences in highest and lowest mean monthly flows;
- Differences in the timing of the highest and lowest monthly flows;
- Variability of monthly and annual flows;
- Frequency and duration of high and low flow spells; and
- Interval between high and low flow spells.

The hydrology panel of the SRA is debating whether these indicators should be "variance-corrected" that is scaled by the range of values observed under natural conditions (SKM, 2002). Both standard and variance-corrected versions of these indicators are discussed in this review (below).

These indicators can be combined to give an overall hydrology index.

$$HI = 1 - \frac{\sqrt{\sum_{n=1}^{N} \left(1 - I_n\right)^2}}{\sqrt{N}}$$

Where: HI = Hydrology Index
N = number of individual indices used to formulate overall index
I_n = n^{th} individual index

4.2.3. Other Australian River Health Assessments

Most states have developed procedures to assess river health, and these generally include an assessment of differences between natural and current hydrology.

The Index of Stream Condition, which is used in Victoria, includes an assessment of the difference in current and natural monthly flows by calculating an index called the Amended Annual Proportional Flow Deviation (AAPFD) (Gehrke et al. 1995; Gehrke, pers. comm.) (see section 4.7).

The AAPFD also forms part of the assessments done in Queensland for Water Allocation Management Plans (WAMPs). There are also additional indicators depending on location which could include assessments based on (Norris et al. 2001):

- Median annual flow;
- Monthly flow variability;
- High flow event frequency;
- Medium flow event frequency;

- Low flow duration;
- No-flow duration;
- Extent of river inundated by dams and weirs.

In the NSW stressed rivers program, the main indicator for unregulated rivers is the estimated proportion of daily flow that has been made available for extraction under existing licenses (Norris et al. 2001).

In the Murray-Darling Basin, over 400 hydrologic indicators, that relate to ecological health, are routinely calculated as part of modelling that is done for water resources planning (Close, pers. comm.).

4.2.4. Other Australian Research

Australian hydrologists and ecologists have developed a large number of indicators in attempts to characterise biologically meaningful differences in flow regimes between rivers in different locations, climate zones and with varying degrees of alternation.

Puckridge et al. used 11 reasonably independent indicators to characterise the variability of flow regimes of 52 rivers in their international survey. The indicators were selected because they were relevant for fish biology.

Marsh and Growns (2002) used 333 hydrologic variables in seven categories to characterise 107 regulated and unregulated streams in Australia. Ninety one of these indicators were reasonably independent. The seven categories were:

1. long-term variables, such as mean daily flow, base flow index, maximum and minimum flow;
2. high-flow variables, i.e. number, duration and magnitude of events above a threshold flow;
3. low-flow variables, i.e. number, duration and magnitude of events below a threshold flow;
4. moving-average variables, i.e. 1-, 30- and 90-day moving averages;
5. cessation-of-flow variables, i.e. duration of periods with zero discharge;
6. variables concerned with the rise and fall of the hydrograph, i.e. durations of rising and falling limbs and comparison of differences in consecutive daily flow; and
7. monthly-flow variables, i.e. distribution of flow between months, and annual variability in monthly flow.

Although these indicators have mainly been used to characterise flow regimes, they may also have application to assessing flow changes caused by human impacts.

4.2.5. International research on hydrologic assessment

The best known international approach to assessing flow regime change is the Indicators of Hydrologic Alteration developed by Richter and others (Richter et al., 1996; Richter et al., 1997; Richter et al., 1998). This is discussed in section 4.12.

Description and discussion of several key hydrologic indicators follows.

4.3. Mean Annual Flow

The difference between the mean annual flow between current and natural conditions shows whether water has been added to, or removed from a river.

A straightforward approach is to base an index on the ratio of average annual current and natural flows. Young et al. (2001) proposed the following.

If $\bar{Q}_c > \bar{Q}_n$ then $A = \frac{\bar{Q}_c}{\bar{Q}_n}$, else $A = \frac{\bar{Q}_n}{\bar{Q}_c}$

Where: A = Mean annual flow index.

$\bar{Q}_c$ = Average current annual flow (ML/year).

$\bar{Q}_n$ = Average natural annual flow (ML/year).

A variance corrected mean annual flow index was developed by SKM (2002) which includes consideration of variation in natural flows.

$$A_{vc} = 1 - \frac{\left|\bar{Q}_c - \bar{Q}_n\right|}{2S_n}$$

where: A_{vc} = variance corrected main annual flow index.

$\bar{Q}_c$ = Average current annual flow (ML/year).

$\bar{Q}_n$ = Average natural annual flow (ML/year).

S_n = standard deviation of the annual flows.

If A_{vc} exceeds 1 it should be set to 1, similarly if it is less than zero, it should be set to zero.

It would also be possible to develop a variance corrected approach based on the range of the natural data rather than 2 standard deviations as is done here.

4.4. Flow duration curve

Flow duration curves are a powerful way of viewing the middle ranges of flow regime. They are less useful for describing extreme high, or extreme low flows. Differences between current and natural flow duration curves can be used to clearly show the effect of human impacts. The challenge is to develop an index that succinctly describes these differences. Young et al. (2001) proposed an index *M* to summarise differences in flow duration curves. This involves calculating the ratio of the current to natural flows at a number of points along a flow duration curve and then taking the average of these ratios.

If $n > c$, then $M = \frac{1}{p}\sum_{i=1}^{p}\frac{c_i}{n_i}$, else $M = \frac{1}{p}\sum_{i=1}^{p}\frac{n_i}{c_i}$

Where: *M* = Flow duration curve difference index.

p = Number of percentiles.

c_i = Current flow at the i^{th} percentile.

n_i = Natural flow at the i^{th} percentile.

A variance corrected version was proposed by SKM (2002) that takes account of the natural variability of flows. If the difference between current and natural flow conditions is outside the natural range of flows, then the impact of flow changes will be counted as being more severe.

$$M_{vc} = 1 - \frac{1}{p}\sum_{i=1}^{p}\frac{\left|\bar{c}_i - \bar{n}_i\right|}{2S_{n,i}}$$

Where: M_{vc} = Variance corrected flow duration curve difference index.

p = Number of percentiles.

$\bar{c}_i$ = Average current flow at the i^{th} percentile.

$\bar{n}_i$ = Average natural flow at the i^{th} percentile.

$S_{n,i}$ = Standard deviation of the natural flow at the i^{th} percentile.

4.5. Seasonal Amplitude

Usually there will be a difference in flows throughout a year with high flows expected in some months and low flows in another. Changes to a hydrologic regime may alter the relative differences between the size of flows in these high flow and low flow months. A seasonal amplitude index summarises this type of flow change.

$$SA = \frac{\left[\frac{h_c}{h_n} + \frac{l_c}{l_l}\right]}{2}$$

where: SA = Seasonal amplitude index.

h_c = Highest current average monthly flow.

h_n = Highest natural average monthly flow.

l_c = lowest current monthly flow.

l_n = lowest natural average monthly flow.

The variance corrected version (SKM, 2002) is as follows.

$$SA_{vc} = 1 - \frac{\left|\bar{a}_c - \bar{a}_n\right|}{2S_n}$$

Where: SA_{vc} = Variance correct seasonal amplitude index.

$\bar{a}_c$ = Average current amplitude (average difference in flow between the high flow and low flow month under current conditions).

$\bar{a}_n$ = Average natural amplitude (average difference in flow between the high flow and low flow month under natural conditions).

S_n = Standard deviation of the natural amplitude.

4.6. Seasonal Period

Flow alternation can shift the month when the highest and lowest flows occur. This change is captured in a seasonal period index.

$$SP = 1 - \frac{1}{12}(\Delta H_m + \Delta L_m)$$

Where: *SP* = Seasonal period difference index.

ΔH_m = Number of months that the high flow month has been shifted.

ΔL_m = Number of months that the low flow month has been shifted.

$\Delta H_m = |H_c - H_n|$ if $|H_c - H_n| \leq 6$.

$\Delta H_m = 12 - |H_c - H_n|$ if $|H_c - H_n| > 6$.

H_c = Month that, on average, under current conditions, has the highest flow (Jan = 1, Feb = 2 etc).

H_n = Month that, on average, under natural conditions, has the highest flow.

ΔL_m is calculated in a similar way to ΔH_m

There is also a variance corrected Seasonal Period Difference index that has been developed by SKM (2002) which is based on the average number of months that the high flows and low flows have been shifted in comparison to the natural variability in the occurrence of the high and low flows. A three step procedure for calculating this index is described in SKM (2002).

4.7. Amended Annual Proportional Flow Deviation (Seasonal Amplitude and Period)

An indicator called the Annual Proportional Flow Deviation is influenced by changes in both seasonal amplitude and period. Gehrke et al. (1995) showed this index was related to diversity of fish species in regulated rivers of Murray-Darling basin. Gehrke pers. comm. proposed a modified version of this indicator (the Amended Annual Proportional flow Deviation) for use where the flow could be zero for one or more months, as could be the case in ephemeral rivers.

$$R_a = \left(\sum_{i=1}^{12} \left(\frac{(c_{ij} - n_{ij})}{\bar{n}} \right)^2 \right)^{\frac{1}{2}}$$

Where: R_a = the amended annual proportional flow deviation (AAPFD).

$\bar{n}$ = the overall mean monthly flow for all months on record.

c_{ij} = is the current flow for month i, in year j.

n_{ij} is the modelled natural flow for that month.

The greater the value of amended annual proportional flow deviation, R_a, the more modified the flow regime is relative to natural conditions. The output would need to be scaled to between zero and one to be consistent with the other indicators discussed here.

The Annual Proportional Flow Deviation has been widely used to assess hydrologic change in NSW, Queensland and Victoria. It is the key indicator in the Index of Stream Condition (Ladson and White, 1999).

4.8. Annual variability

Flow changes can affect the magnitude, timing and variability of a natural flow regime. A straightforward index that captures change in variability is the ratio of the coefficients of variation between natural and current conditions (SKM, 2002).

$$AV = \frac{ACV_n}{ACV_c}$$

where: AV = Annual variation index.

ACV_c = Current annual coefficient of variation.

ACV_n = Natural annual coefficient of variation.

4.9. Monthly variability

A similar index can describe changes in the variation of monthly flows (SKM, 2002).

$$MV = \frac{MCV_n}{MCV_c}$$

where: MV = Monthly variation index

MCV_c = Current monthly coefficient of variation

MCV_n = Natural monthly coefficient of variation

4.10. Spells

Another important way of quantifying flow changes is to look behaviour of high flow and low flow events under current and natural conditions. A key idea for the this type of analysis is the concept of a spell (Figure 3). A spell is an individual high flow or low flow event. High flows are commonly described as those greater than a flow that is exceeded 10% of the time. Low flows are generally considered as those that are lower than a flow exceeded 90% of the time (Donald et al. 1999).

Indices have been developed to describe:

- The number of spells;

- The duration of spells;
- The interval between spells; and
- Frequency of start month of spell (Donald et al. 2002).

A Spells Number Index, a Spells Duration Index and a Spells Interval Index are described in SKM (2002). Sample calculations are provided for the Thomson River (SKM, 2002) and Ovens River (SKM, 2003).

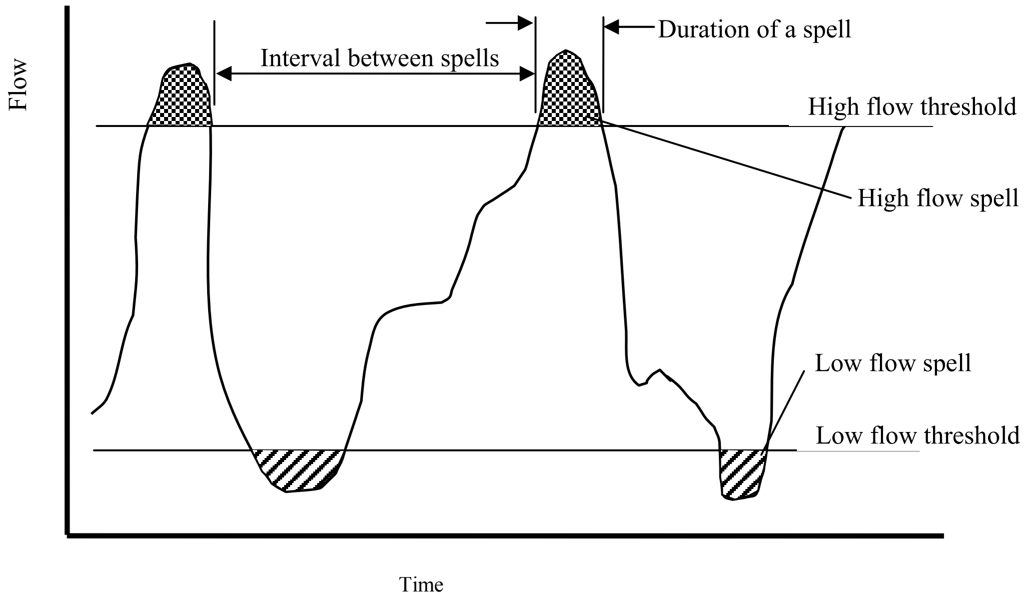

Figure 3 – High flow and low flow events, known as spells

4.10.1. Spells Number Index

The Spells Number Index, summaries the changes in the number of spells that occur under current and natural conditions.

$$SPN_i = \frac{SPN_{i,c}}{SPN_{i,n}} \text{ (if } SPN_{i,c} > SPN_{i,n}\text{), or } SPN_i = \frac{SPN_{i,n}}{SPN_{i,c}} \text{ (if } SPN_{i,n} > SPN_{i,c}\text{)}$$

Where: SPN_i = Spells Number Index for the i^{th} percentile threshold (usually the 10% or 90% flow are used).

$SPN_{i,c}$ = Number of spells under current conditions for the i^{th} percentile flow. This could be the average number of spells per year for a multi-year record.

$SPN_{i,n}$ = Number of spells under natural conditions for the i^{th} percentile flow. This could be the average number of spells per year for a multi-year record.

It is also possible to develop a variance corrected version of this index, using a similar approach to that for the mean annual flow index above.

$$SPN_{vc,i} = 1 - \frac{\left| \overline{SPN}_{i,c} - \overline{SPN}_{i,n} \right|}{2S_{i,n}}$$

Where: $\overline{SPN}_{i,c}$ = the average number of spells per year for current conditions for the i^{th} percentile flow.

$S_{i,n}$ = is the standard deviation in the natural number of spells per year for the i^{th} percentile flow.

4.10.2. Spells Duration Index

The change in the duration of spells can be measured using a Spells Duration Index

$$SPD_{vc} = 1 - \left[\frac{\overline{SPD}_{i,c} - \overline{SPD}_{i.n}}{2S_{i,n}} \right]$$

Where: SPD_{vc} = Variance corrected Spells Duration Index.

$\overline{SPD}_{i,c}$ = average duration of spells above (or below) the i^{th} percentile flow, under current conditions.

$S_{i,n}$ = Standard deviation in the duration of spells for the i^{th} percentile flow under natural conditions.

4.10.3. Spells Interval Index

Any changes in intervals between spells can be measured using a Spells Interval Index

$$SPI_{vc} = 1 - \left[\frac{\overline{SPI}_{i,c} - \overline{SPI}_{i,n}}{2S_{i,n}} \right]$$

Where: SPI_{vc} = Variance corrected spells interval index

$\overline{SPI}_{i,c}$ = average interval between spells for the i^{th} percentile flow, under current conditions.

$S_{i,n}$ = Standard deviation of the interval between spells for the i^{th} percentile flow under natural conditions.

This could be calculated for both high and low flow percentiles.

4.11. Maribyrnong Aggregate Index

The innovate feature of this index is that a number of facets of hydrologic change are assessed, which vary depending on the flow season. Aspects are chosen on the basis that they are biological relevant. A weighting procedure is used to produce a single number which summaries hydrologic change (Heron et al. 2002).

The indicators used in the Maribyrnong Aggregate Index include:

- Average daily flow;
- Median daily flow;
- 80th percentile exceedence flow;
- Coefficient of variation;
- Zero flows – frequency per 100 years;
- Zero flows – mean duration of spells;
- Freshes (flows greater than median daily flow) – frequency per 100 years;
- Freshes (flows greater than median daily flow) – mean duration of spell;
- Very high flows (flows greater than the 20th percentile exceedence flow) – frequency;
- Very high flows (flows greater than the 20th percentile exceedence flow) – duration.

The use of these indicators in three flow seasons (low, transitional and high) is documented in Table 5.

All the indicators are based on the ratio of current and natural values. For example, the average daily flow indicator is based on the ratio of current to natural average daily flow. This ratio is then reported as a percentage change which is used to determine a rating (Table 6). All the ratings for a season are summed and compared to the maximum possible value to determine an overall aggregate index score (Table 7). This can be related to a description of flow stress (Table 8). Note that for the Maribyrnong Aggregate Index, values range from 1 to zero, with zero indicating that flow are close to natural. This is the opposite convention to most of the other hydrologic indicators reviewed here.

Table 5 – Indicators and weightings for the Maribyrnong Aggregate Index (Heron et al. 2002)

Indicator	Weight
Low flow season	
Average daily flow	0.05
Median daily flow	0.15
80^{th} percentile exceedence flow	0.2
Coefficient of Variation (Cv)	0.05
Zero flows – frequency per 100 years	0.15
Zero flow – mean duration of spells	0.1
Freshes (flows > median) frequency per 100 years	0.2
Freshes (flows > median) mean duration of spells	0.1
Total	**1.00**
Transitional Seasons	
Average daily flow	0.05
Median daily flow	0.35
Coefficient of Variation Cv	0.05
Freshes (flows > median) frequency per 100 years	0.3
Freshes (flows > median) mean duration of spells	0.25
Total	**1.00**
High Flow Season	
Average daily flow	0.1
Median daily flow	0.35
Coefficient of Variation (Cv)	0.1
Very high flows (>20% flow)	0.25
Very high flows (>20% flow) – mean duration of spells	0.2
Total	**1.00**

Table 6 – Rating of indicators used in the Maribyrnong Aggregate Index (Heron et al. 2002)

(Indicator based on current flows)/(Indicator based on natural flows)		
Decrease	**Increase**	**Rating**
90-100%	100-150%	0
67-89%	150-200%	1
50-66%	200-500%	2
<50%	>500%	3

Table 7 – Sample calculation of the Maribyrnong Index (Heron et al. 2002)

Indicator	**Natural**	**Current**	**% of natural**	**Rating**	**Weight**	**Score**
Mean (ML/d)	225	140	62	2	0.05	0.10
Median (ML/d)	40	20	50	2	0.15	0.3
80% flow (ML/d)	20	4	20	3	0.02	0.6
Cv	3.15	2.95	94	0	0.05	0.00
Zero flow frequency (per 100 years)	10	98	980	3	0.15	0.45
Zero flow duration (days)	1.2	4.5	375	2	0.1	0.2
Freshes frequency (per 100 years)	123.8	72.3	58	2	0.2	0.4
Freshes duration (days)	5.7	2.1	36	3	0.1	0.3
Sum						2.35
Score	Sum/3, where 3 is the maximum possible sum					0.78

Table 8 – Descriptions of scores from the Maribyrnong Aggregate Index (Heron et al. 2002).

Score	Description
1.00 – 0.81	Very High Stress
0.80 – 0.67	High Stress
0.66 – 0.51	Moderate Stress
0.50-0.33	Low Stress
0.32-0.00	Very low stress.

4.12. Indicators of Hydrologic Alteration

The Nature Conservancy in the US has developed a suite of 33 Indicators of Hydrologic Alteration (IHA) that can be calculated for each year of record (Richer et al. 1996; 1997; 1998) (Table 9). These indicators have now been largely superseded by those developed for the Sustainable Rivers Audit.

Further information on IHA is available at http://www.freshwaters.org/eswm/iha/ Software to calculate these indicators is available from $US200 from Smythe Scientific Software http://www.smythescisoft.com/.

IHA is a key part of the 'Range of Variability Approach' (RVA) which can be used to set flow targets when restoring rivers. The essence of this approach is to make flow regimes in impacted rivers more natural by aiming to return the IHA to within natural limits.

Table 9 – Indicators of Hydrologic Alteration (Richter et al. 1996)

IHA statistics group	Regime Characteristics	Hydrologic parameter
Group 1: Magnitude of monthly water conditions	Magnitude, Timing	Mean value for each calendar month
Group 2: Magnitude and duration of annual extreme water conditions	Magnitude, Duration	Annual minima 1-day means Annual maxima 1-day means Annual minima 3-day means Annual maxima 3-day means Annual minima 7-day means Annual maxima 7-day means Annual minima 30-day means Annual maxima 30-day means Annual minima 90-day means Annual maxima 90-day means
Groups 3: Timing of annual extreme water conditions	Timing	Julian date of each annual 1 day maximum Julian date of each annual 1 day minimum
Group 4: Frequency and duration of high and low pulses	Magnitude, Frequency, Duration	No. of high pulses each year No. of low pulses each year Mean duration of high pulses within each year Mean duration of low pulses within each year
Group 5: Rate and frequency of water condition changes	Frequency, Rate of change	Means of all positive differences between consecutive daily means Means of all negative differences between consecutive daily values No. of rises No. of falls

4.13. Hydraulic Indicators

Hydrologic indicators consider flow magnitudes and timing but ignore physical context of the river channel and floodplain. A better approach is to use hydraulic indicators that can describe flow mechanics, such as force, depth, velocity, shear stress, Reynolds number, Froude number, frequency of overbank flooding etc, as these features are clearly more important to biota. Hydrologic indicators are only relevant because they may be correlated with hydraulic conditions and events, why not use indicators that are directly based on these conditions and events?. The downside is that they require more data and are computationally intensive.

Hydraulic (in addition to hydrologic) indictors have been included in recent environmental flow assessments undertaken by the Cooperative Research Centres for Catchment Hydrology and Freshwater Ecology (Stewardson, 2001; Cottingham et al. 2001; Stewardson and Cottingham, 2002).

If sufficient data was available, or could be collected, then indicators could be developed to describe the changes in key hydraulic conditions and events under current and natural flows. These indicators are likely to include:

- Bed scouring or some other indicator of pool formation;
- Sediment transport or some other indicator of pool infilling;

- Spawning and migration cues for biota;
- Channel forming flow – whether changes to flow are likely to make the channel larger or smaller; and
- Frequency of overbank flow – how often there is transfer of water, nutrients and carbon between channels and floodplains.

Data requirements include:

1. Surveys of channel cross sections and long sections;
2. Current and natural daily flow data;
3. Descriptions of bed material size;
4. Information on stage height at key locations for particular flows;
5. Information on stream roughness characteristics

The first two items on this list are critical, the other information would allow a greater range of indicators to be calculated.

4.14. Surrogate Indicators

It some cases, there may not be sufficient information to allow calculation of any hydrologic indicators. If there is no flow data, but current flows are close to natural, than it is appropriate to set hydrologic indicators to their 'natural' level. No calculations are required. However, if flow changes are expected, even if they are not measured, it will be necessary to use surrogate indicators.

Surrogate indicators are based on direct measurements of the feature or change that is thought to be influencing flow. Often this will be related to land use. Example surrogate indicators include capacity of farms in a catchment, or extent of urbanisation.

The requirements for, and selection of, surrogate indicators, will depend on the data that is available at the sites selected for this project.

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Appendix 1 – Summary of Geomorphic Indicators

Table A1 - Australian River Assessment System: AusRivAS Physical Assessment Protocol
Summary list of control and response variables included in the Australian River Assessment System: AusRivAS Physical Assessment Protocol. Office or field collection indicates whether the variable is collected in the field, or collected in the office (Source: Parsons et al. 2002)

CONTROL VARIABLES		
Category	**Variable**	**Office or field collection**
Position of the site in the catchment	Latitude	Field
	Longitude	Field
	Altitude	Office
	Distance from source	Office
	Link magnitude	Office
Water chemistry	Alkalinity	Field
Catchment characteristics	Total stream length	Office
	Drainage density	Office
	Catchment area upstream of the site	Office
	Elongation ratio	Office
	Relief ratio	Office
	Form ratio	Office
	Mean catchment slope	Office
	Mean stream slope	Office
	Catchment geology	Office
	Rainfall	Office
Valley characteristics	Valley shape	Field
	Channel slope	Office
	Valley width	Office
Planform channel features	Sinuosity	Office
Landuse	Catchment landuse	Office
	Local landuse	Field
Hydrology	Index of mean annual flow	Office

	Index of flow duration curve difference	Office
	Index of flow duration variability	Office
	Index of seasonal differences	Office
RESPONSE VARIABLES		
Category	**Variable**	**Office or field collection**
Physical morphology and bedform	Extent of bars	Field
	Type of bars	Field
	Channel shape	Field
Cross-sectional dimension	Bankfull channel width	Both
	Bankfull channel depth	Both
	Baseflow stream width	Both
	Baseflow stream depth	Both
	Bank width	Both
	Bank height	Both
	Bankfull width to depth ratio	Both
	Bankfull cross-sectional area	Both
	Bankfull wetted perimeter	Both
	Baseflow cross-sectional area	Both
	Baseflow wetted perimeter	Both
Substrate	Bed compaction	Field
	Sediment angularity	Field
	Bed stability rating	Field
	Sediment matrix	Field
	Substrate composition	Field
Planform channel features	Planform channel pattern	Office
	Extent of bedform features	Field
Floodplain characteristics	Floodplain width	Field
	Floodplain features	Field
Bank characteristics	Bank shape	Field
	Bank slope	Field
	Bank material	Field
	Bedrock outcrops	Field

	Artificial bank protection measures	Field
	Factors affecting bank stability	Field
Instream vegetation and organic matter	Large woody debris	Field
	Macrophyte cover	Field
	Macrophyte species composition	Field
Physical condition indicators and habitat assessment	USEPA epifaunal substrate / available cover habitat score (high and low gradient streams)	Field
	USEPA embeddedness habitat score (high gradient streams) or pool substrate characterisation habitat score (low gradient streams)	Field
	USEPA velocity / depth regime habitat score (high gradient streams) or pool variability habitat score (low gradient streams)	Field
	USEPA sediment deposition habitat score (high and low gradient streams)	Field
	USEPA channel flow status habitat score (high and low gradient streams)	Field
	USEPA channel alteration habitat score (high and low gradient streams)	Field
	USEPA frequency of riffles (or bends) habitat score (high gradient streams) or channel sinuosity habitat score (high and low gradient streams)	Field
	USEPA bank stability habitat score (high and low gradient streams)	Field
	USEPA bank vegetative protection habitat score (high and low gradient streams)	Field
	USEPA riparian vegetative zone width habitat score (high and low gradient streams)	Field
	USEPA total habitat score (high and low gradient streams)	Field
	Channel modifications	Field
	Artificial features	Field
	Physical barriers to local fish passage	Field
Riparian vegetation	Shading of channel	Field
	Extent of trailing bank vegetation	Field
	Riparian zone composition	Field
	Native and exotic riparian vegetation	Field
	Regeneration of native woody vegetation	Field
	Riparian zone width	Field
	Longitudinal extent of riparian vegetation	Field
	Overall vegetation disturbance rating	Field

Site observations	Local impacts on streams	Field
	Turbidity (visual assessment)	Field
	Water level at the time of sampling	Field
	Sediment oils	Field
	Water oils	Field
	Sediment odours	Field
	Water odours	Field
	Basic water chemistry and nutrients	Field
	Filamentous algae cover	Field
	Periphyton cover	Field
	Moss cover	Field
	Detritus cover	Field

Table A2 – Summary of possible geomorphic indicators

Possible Geomorphic Indicator	**Assessment based on**	**Reference**
Bed composition	Diversity of substrate type (greater diversity implies higher rating)	Barmuta et al. 1992; Petersen, 1992
Sediment accumulation	Modelled sediment deposition.	Norris et al. 2001
Feel and appearance of stony substrate	Rounding, sharpness of edges and colour	Petersen, 1992
Pools and riffles	Proportion and spacing of stream length as pools and riffles	Barmuta et al. 1992; Petersen, 1992
Erosion and sedimentation	Visual assessment and categorisation of erosion and sedimentation.	Barmuta et al. 1992; Ladson and White, 1999; Petersen, 1992
Channel form, plans and dimensions	Comparison with reference	Anderson, 1993a; Anderson 1993b; Jackson and Anderson, 1994.
Banks, physical condition and process	Comparison with reference	Anderson, 1993a; Anderson 1993b; Jackson and Anderson, 1994.
Bed and bars, physical condition and process	Comparison with reference	Anderson, 1993a; Anderson 1993b; Jackson and Anderson, 1994.
Longitudinal connectivity	Number of dams or barriers upstream and downstream	Norris et al. 2001; Ladson and White, 1999.
Lateral connectivity	Extent of levees in a reach	Norris et al. 2001;
Channel structure	Width to depth ratio and capacity in comparison to annual flood	Petersen, 1992